The Monitoring Board for the Calibration System of the Muon g-2 Experiment

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New Perspectives 2016

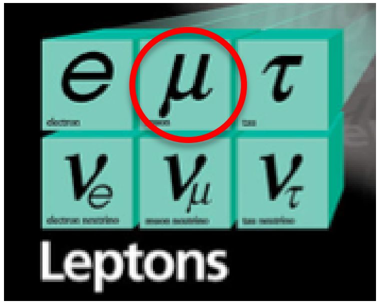
Fermilab | 14 June 2016

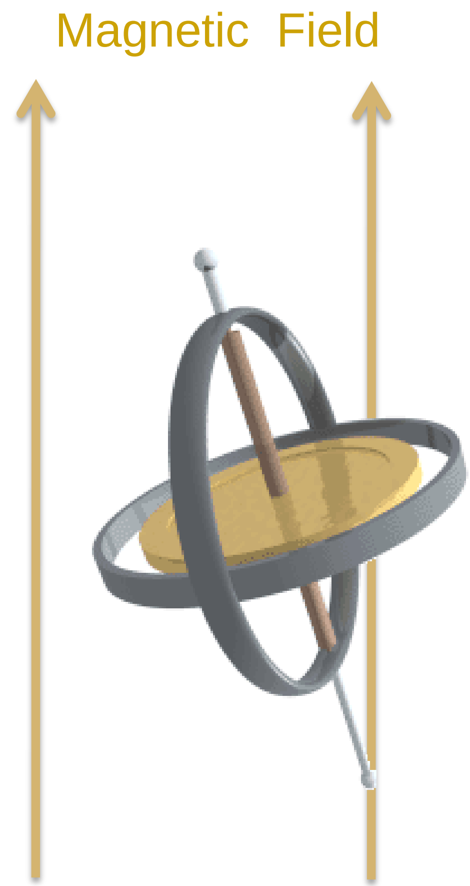
Università degli Studi di Napoli Federico II

Overview

- Experiment Background
- Laser Calibration System
- Monitoring Board
- Summary

Experiment Background: “Precision” frontier

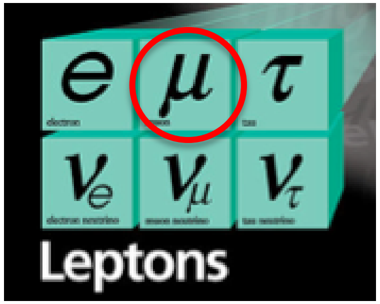




Does particle behavior match Standard Model predictions?

- Mass?
- Production rates?
- Decay rates?
- Interactions with other particles or fields (e.g. magnetic moment)

Experiment Background: “Precision” frontier



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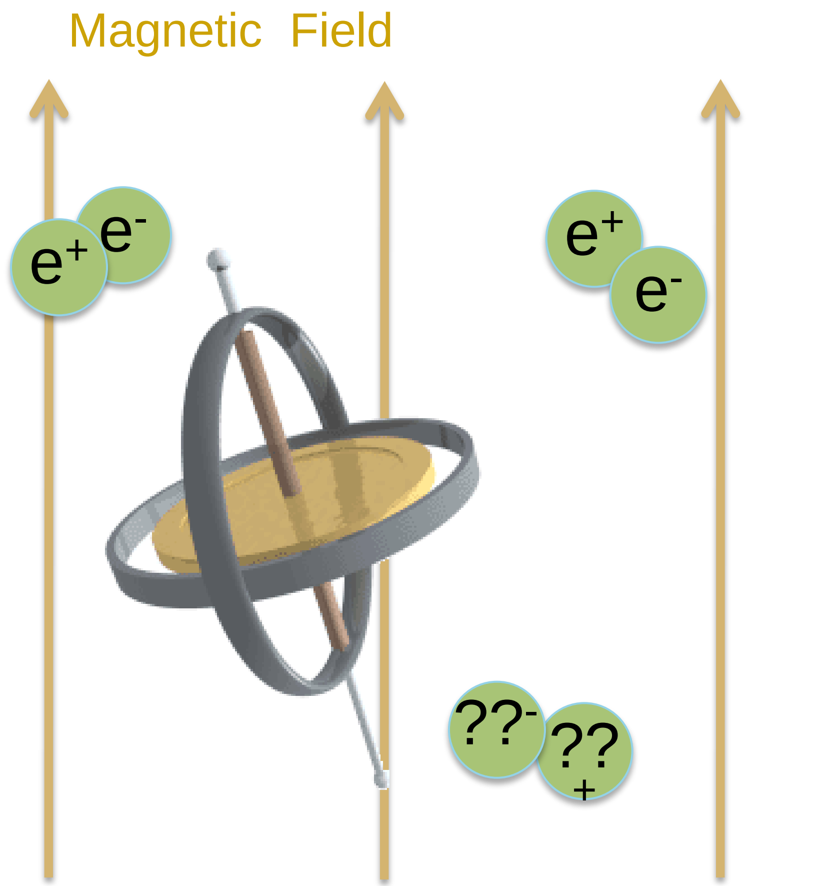
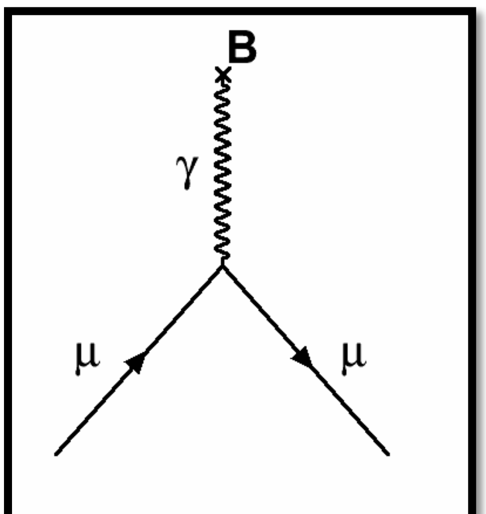


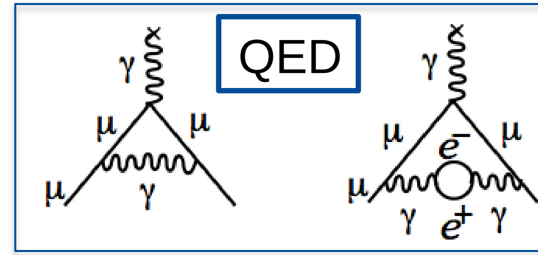
Experiment Background: Magnetic moment

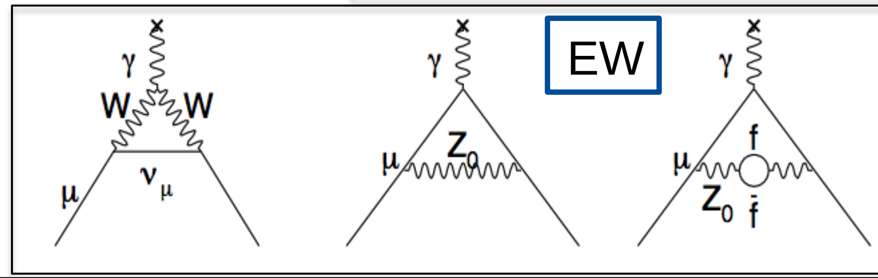
$$\vec{\mu} = g\,\frac{q}{2m}\,\vec{S}$$

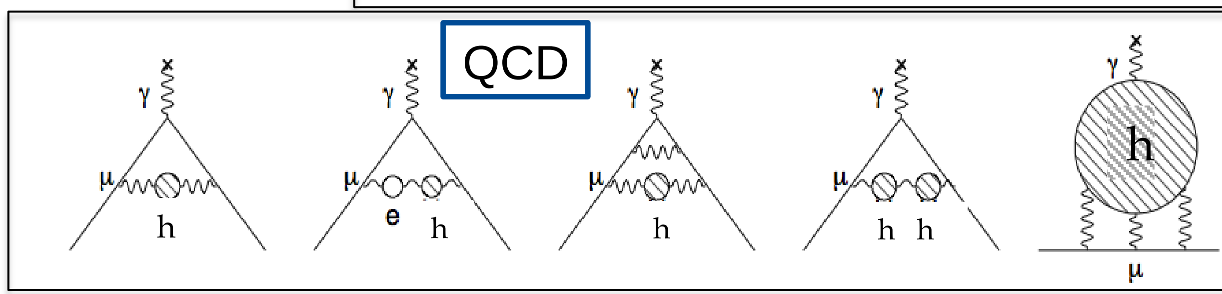
- Dirac theory: a charged, spin ½ elementary point particle has

  g ≡ 2









$$a_\mu^{SM} = (g_\mu^{SM}-2)/2 = a_\mu^{QED} + a_\mu^{EW} + a_\mu^{QCD}$$

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Experiment Background: Testing the anomalous magnetic moment

$$a_\mu^{\text{Expt.}} - a_\mu^{\text{SM}} = (260 \pm 78) \times 10^{-11} \quad (3.3\ \sigma)$$

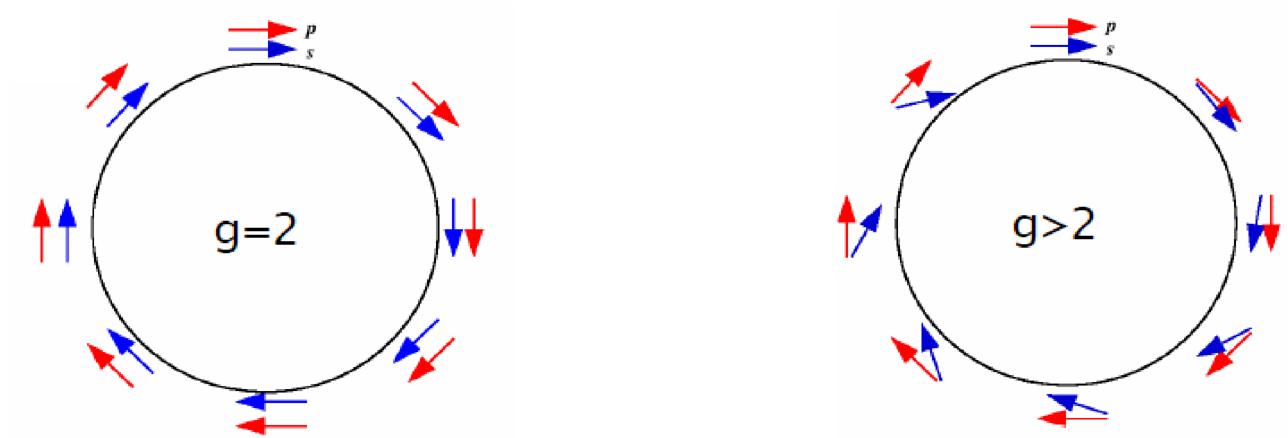
$$a_\mu^{\text{Expt.}} = a_\mu^{\text{SM}} + a_\mu^{\text{New Physics}}$$

- E-821 at BNL
  - Latest measurement of the anomalous magnetic moment of a muon had a **3.3σ discrepancy** from SM
  - Uncertainty mainly due to HVP and HLBL terms in QCD prediction

- E-989 at Fermilab
  - More than 21 times the amount of statistics than predecessor E-821
  - δa_μ^{exp} = .54 ppm to .14 ppm improvement
  - Reduced pion contamination, segmented detectors and an improved storage ring kicker

Experiment Background: Muons in a storage ring

1. Start with polarized muon beam (from pion decay)
2. Cyclotron frequency: $\omega_c = \dfrac{e}{m\,\gamma} B$
3. Spin precession frequency: $\omega_S = \dfrac{e}{m\,\gamma} B\,(1 + \gamma\, a_\mu)$



→ momentum
→ spin

$$\omega_a = \omega_S - \omega_C = e/m\; a_\mu\; B$$

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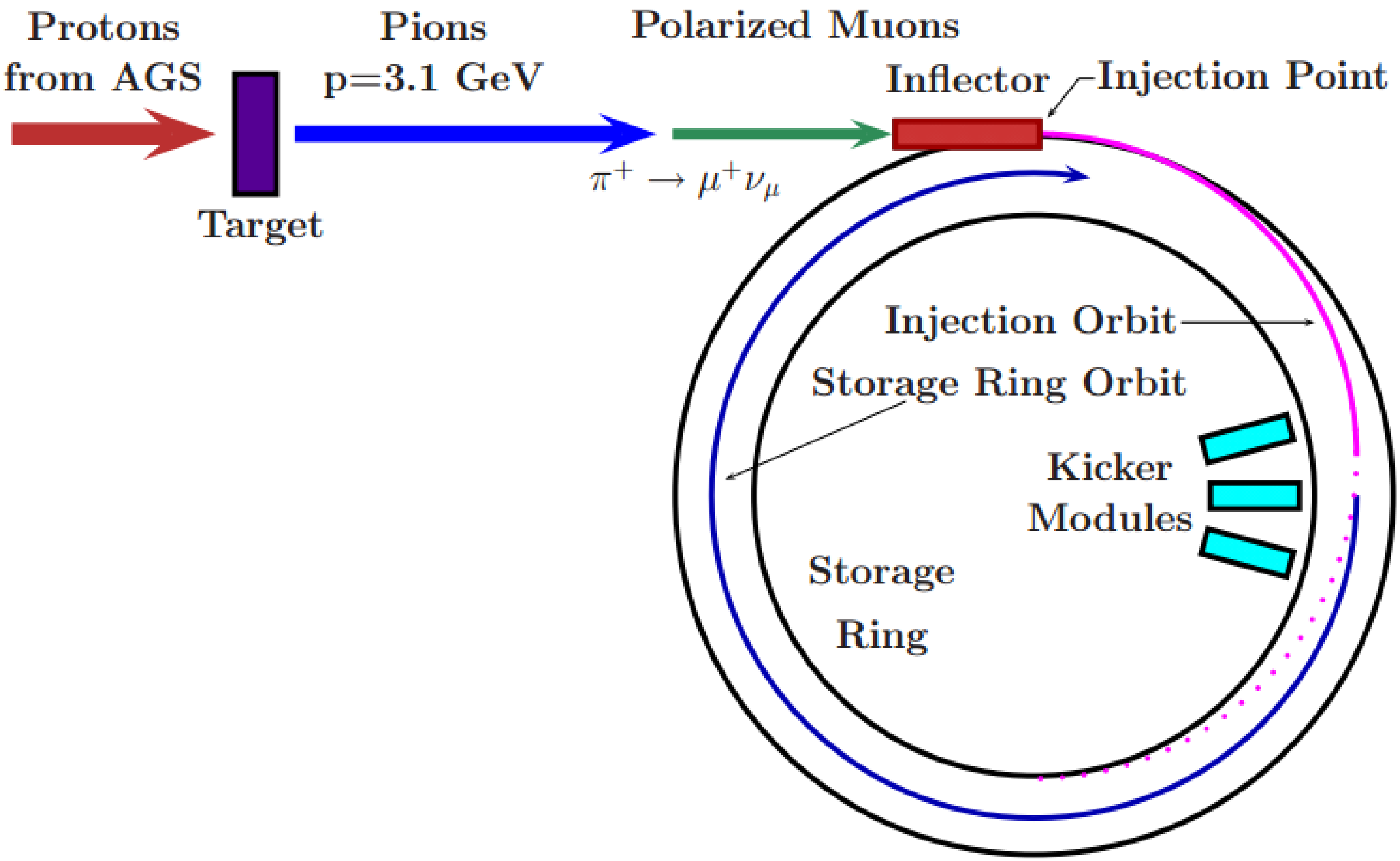
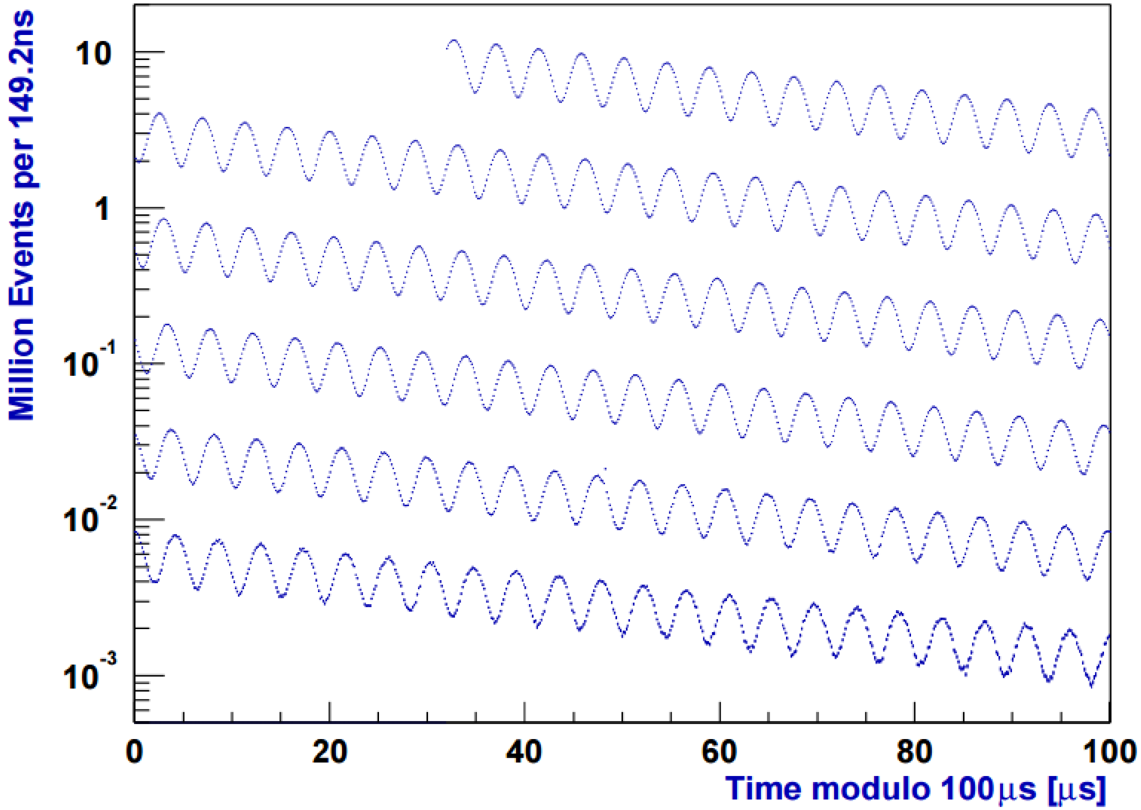


Jegerlehner & Nyffeler, Phys. Rept. 477 (2009) 1-110, arXiv:0902.3360v1

Experiment Background: Muons in a storage ring

$$N(t) = N_0 e^{-t/\tau} \left(1 + A cos(\omega_a t + \phi)\right)$$

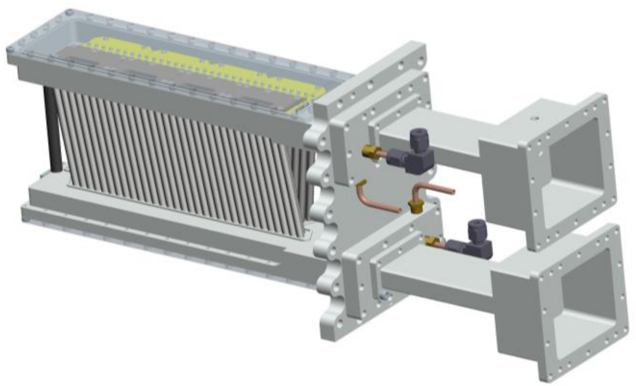
τ is the muon lifetime, the magnitude of the amplitude A is determined by the energy cut, and the phase ϕ depends on the initial polarization of the muon ensemble.

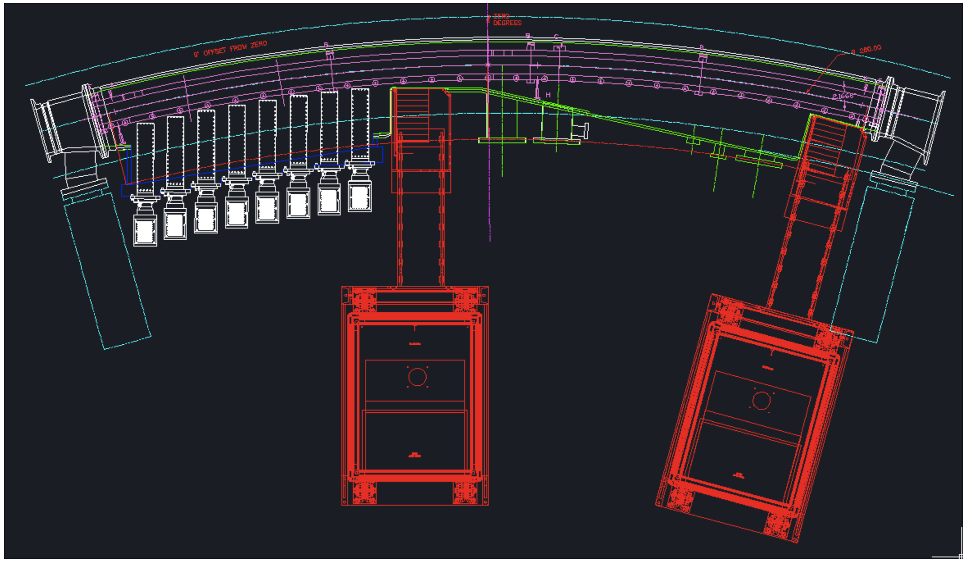


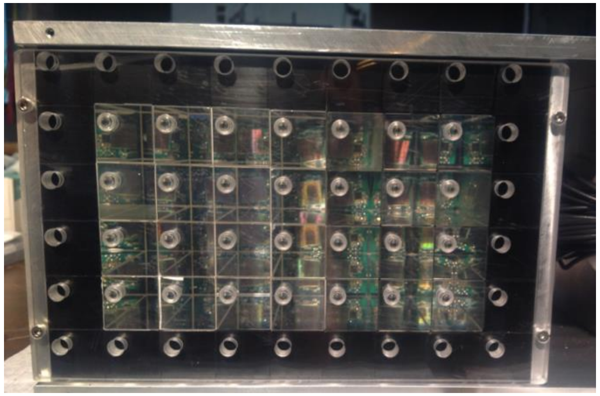
- Self-analyzing decay:
  - Higher energy positrons emitted preferentially in direction of muon spin
- Spectrum distortions
  - Pileup, gain stability
  - Beam effects, losses

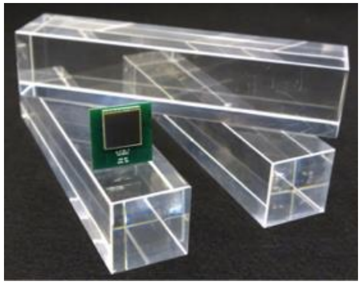
Time spectrum of decay positrons above 1.8 GeV/c^2. Modulation is at frequency ω_a which is proportional to a_μ (Courtesy of the E821 collaboration)

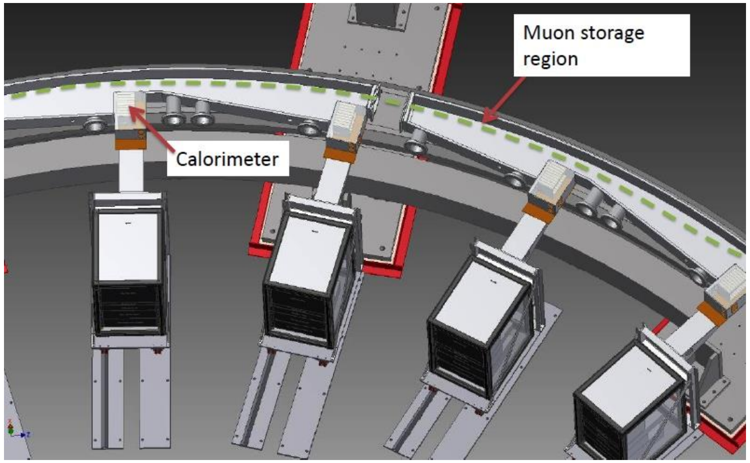
Experiment Background: Instrumentation Upgrades











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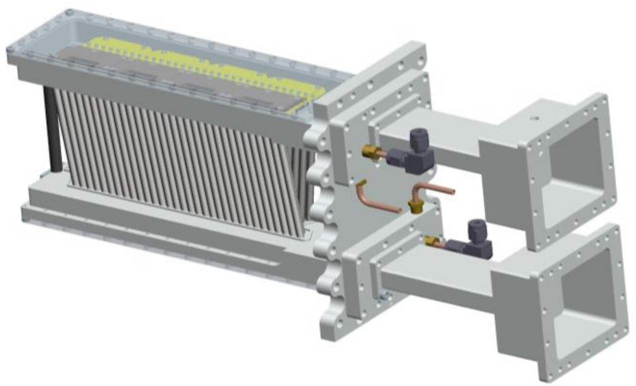

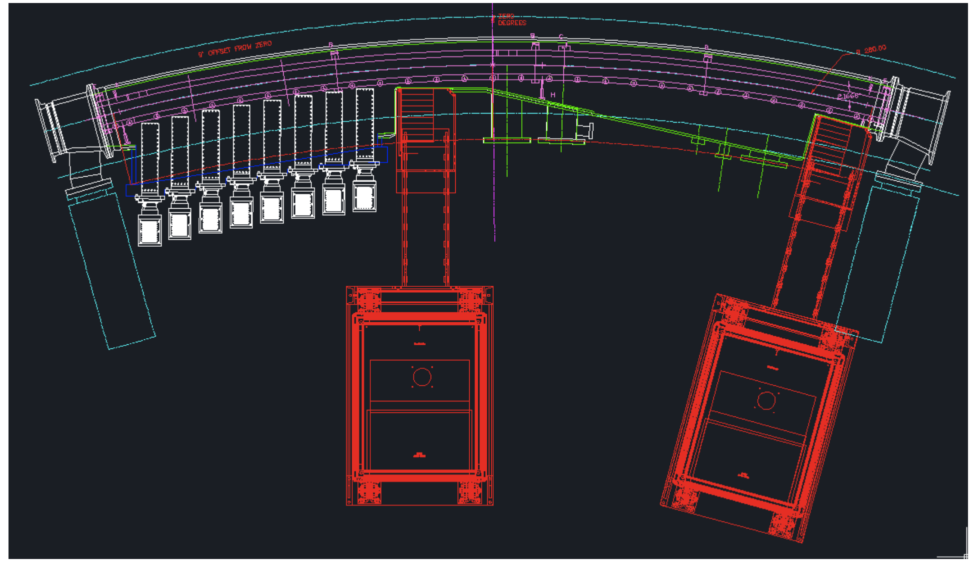

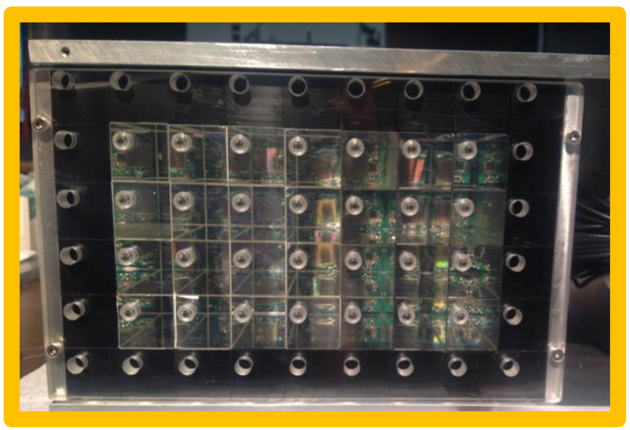

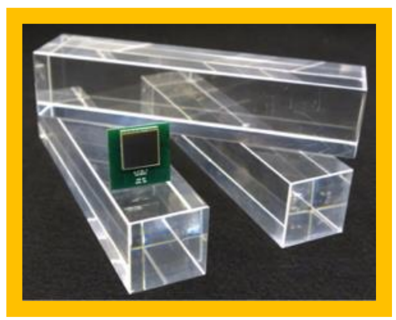

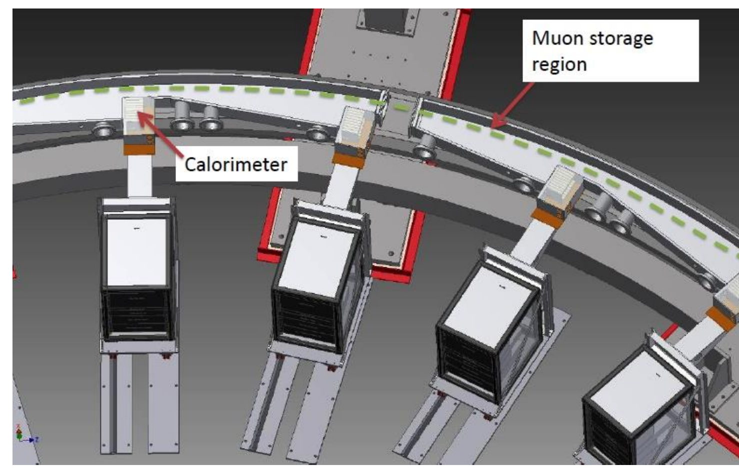

Segmented compact PbF2 Cherenkov

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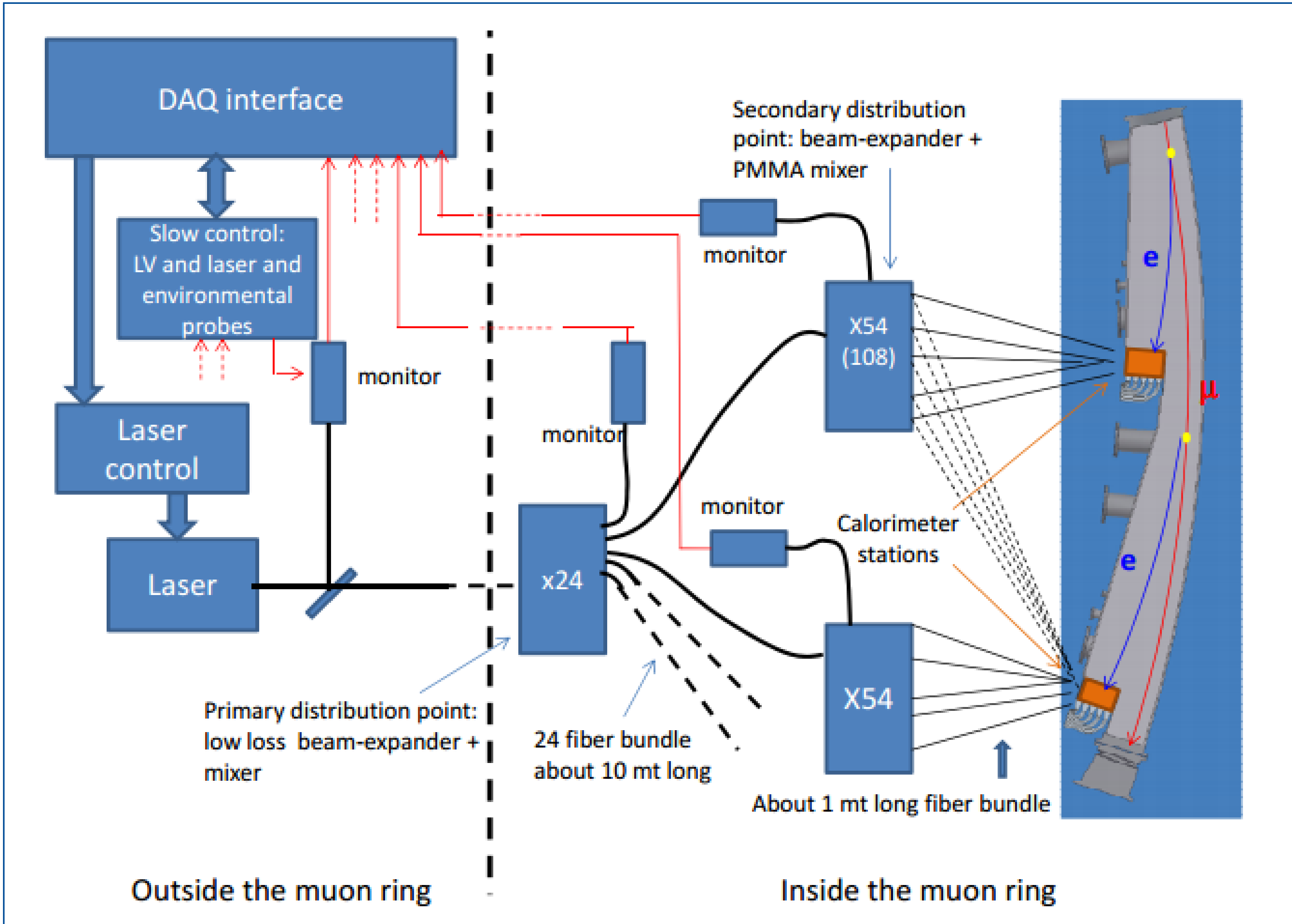
Laser Calibration System: Variable gain

- Gain fluctuations
  - Dangerous "short term" (within 700 μs fill) fluctuations alter energy reconstruction and raise systematic error on ω_a to intolerable levels (>.01 ppm)

- Calibration approach
  - Monitor gain (G_{cal}) of all calorimeter elements by exciting and monitoring the entire system periodically with a **common** light source (in principle, can ignore light source fluctuations)
  - Statistical fluctuations in recorded data must be smaller than variations in G_{cal} (<.1% per hour)



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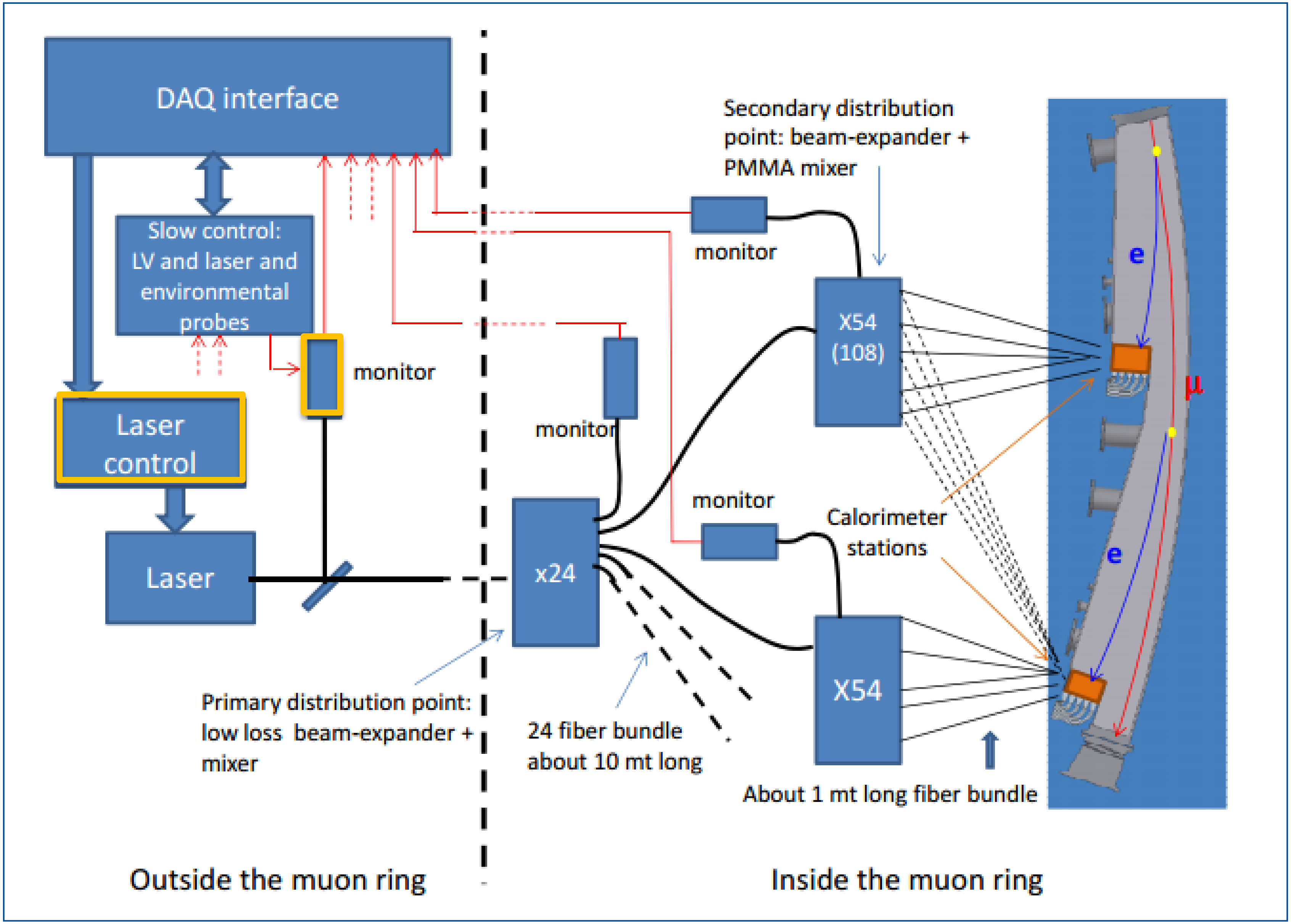
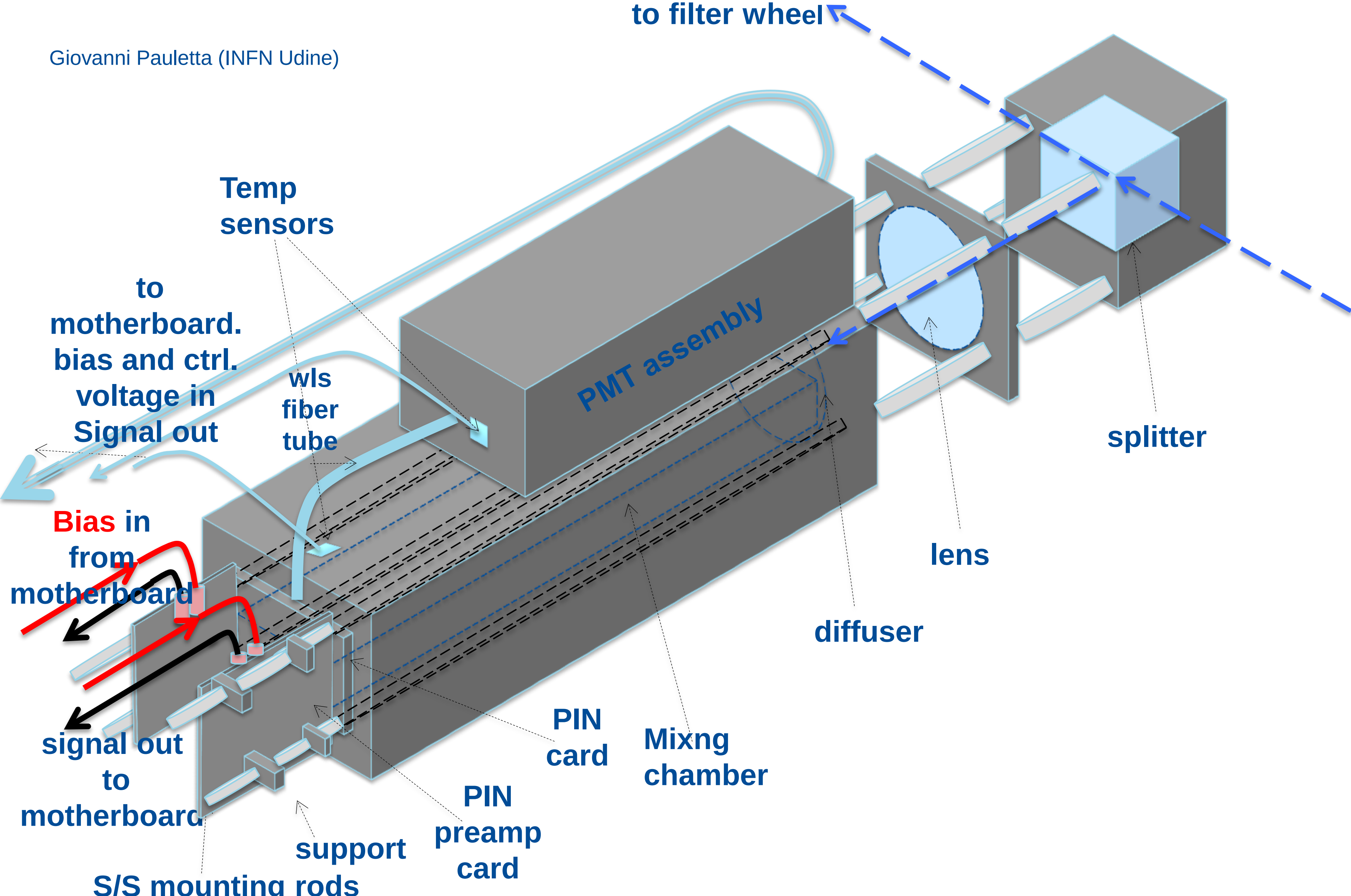

DAQ interface
Slow control: LV and laser and environmental probes
monitor
Laser control
Laser
monitor
x24
Secondary distribution point: beam-expander + PMMA mixer
monitor
X54 (108)
monitor
Calorimeter stations
X54
e
μ
e
Primary distribution point: low loss beam-expander + mixer
24 fiber bundle about 10 mt long
About 1 mt long fiber bundle
Outside the muon ring
Inside the muon ring


to filter wheel
Temp sensors
to motherboard. bias and ctrl. voltage in Signal out
wls fiber tube
PMT assembly
splitter
lens
diffuser
Bias in from motherboard
signal out to motherboard
PIN card
Mixng chamber
PIN preamp card
support
S/S mounting rods

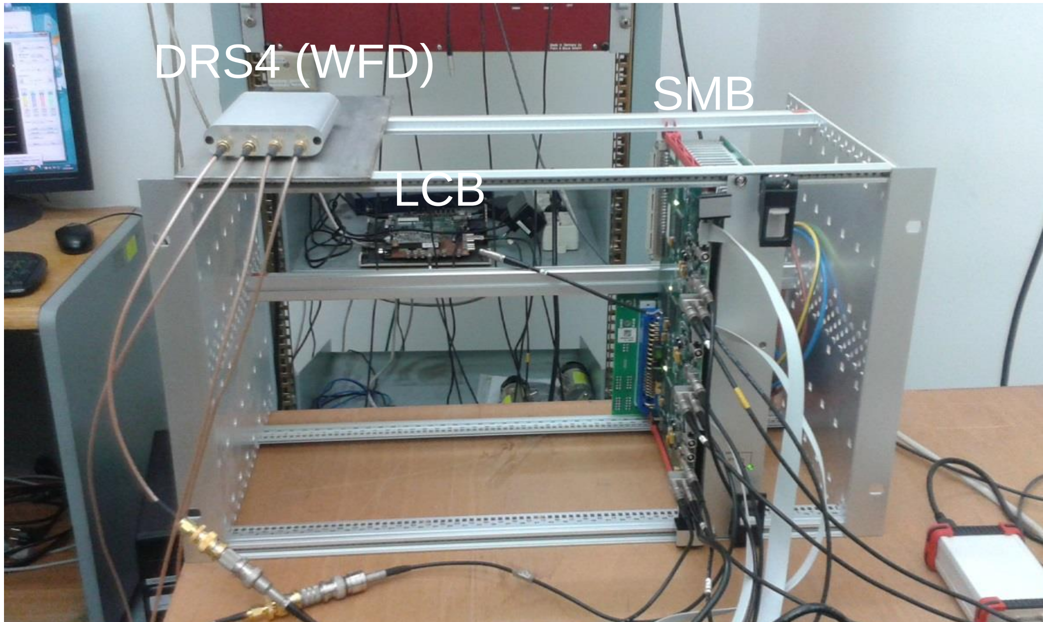
Laser Calibration System: SM detectors

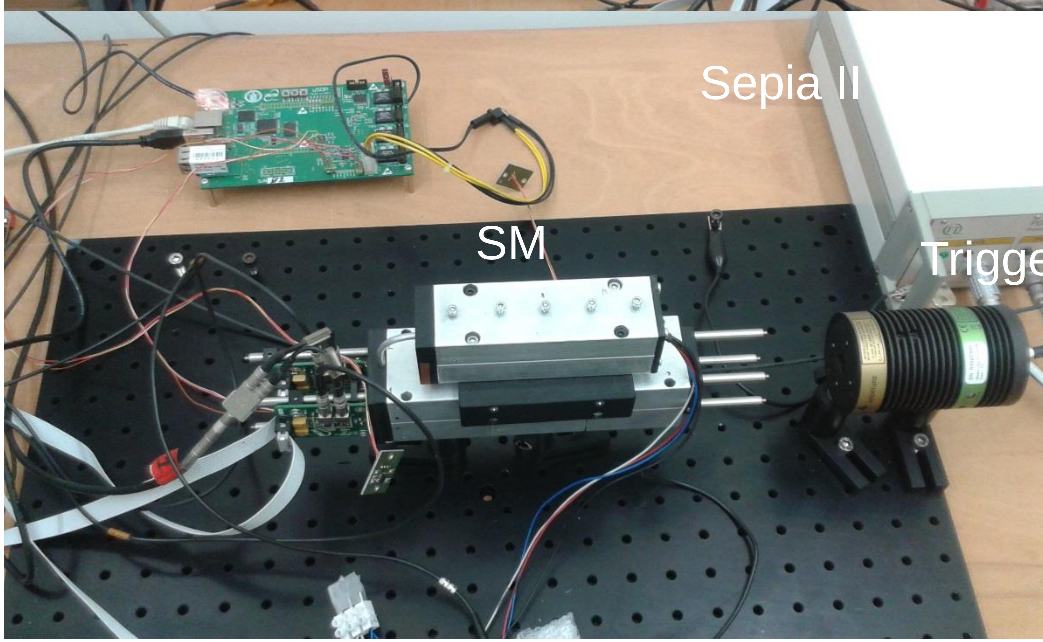
Each Source Monitor detects light using 3 independent detectors, 2 PIN diodes and 1 PMT to observe for eventual beam pointing effects.

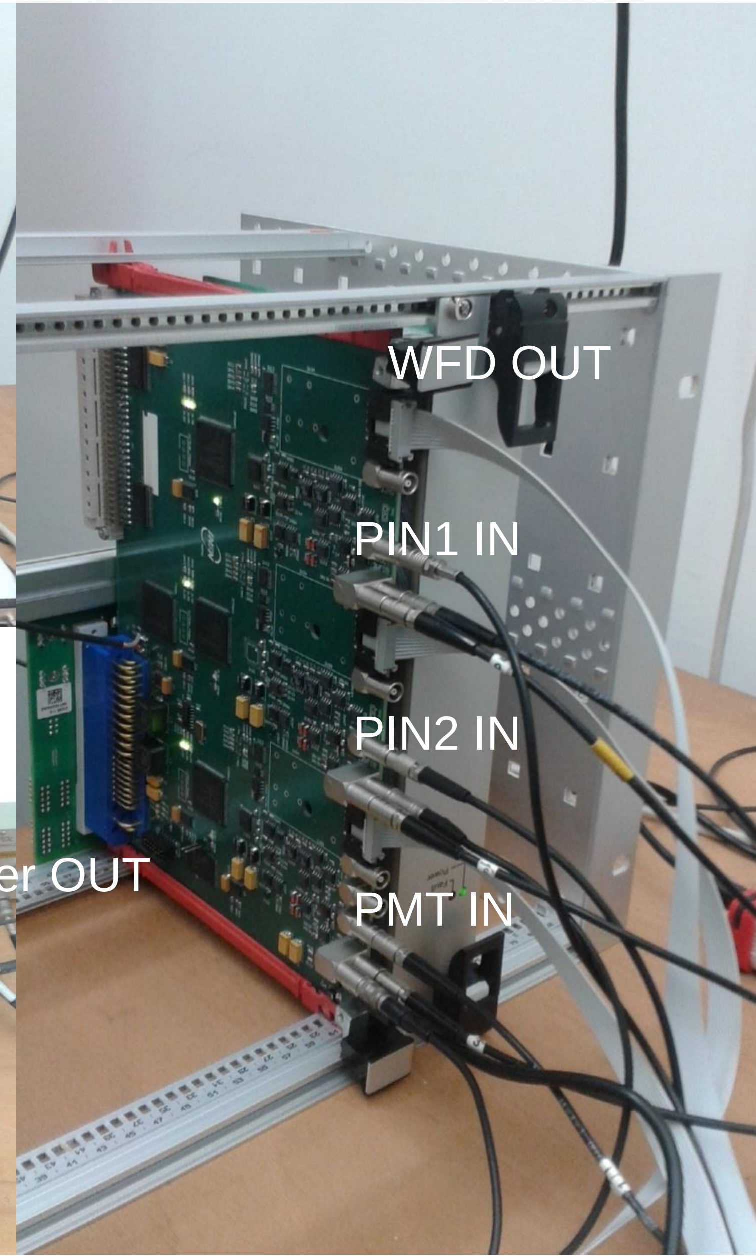
- PIN photodiodes (S1722-02)
  - amplified by custom frontend electronics
  - High photoefficiency (> 70%)
  - Fast (rise time ~ ns) – can be shaped according to necessity
  - Stable inherent gain (rise time and amplitude depend on bias but charge is nearly independent of bias voltage)
  - Overall detector gain stability depends essentially on frontend electronics which are designed to optmize stability

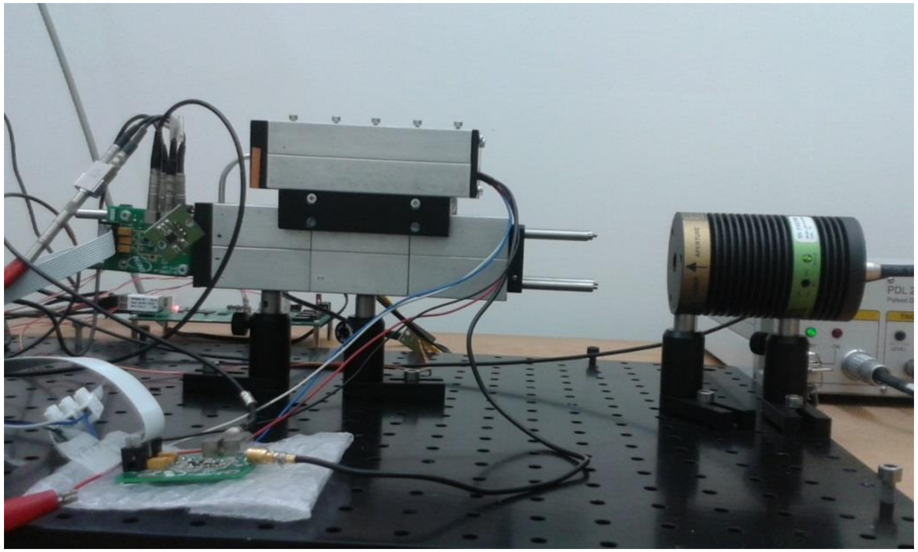
Laser Calibration System: SM detectors

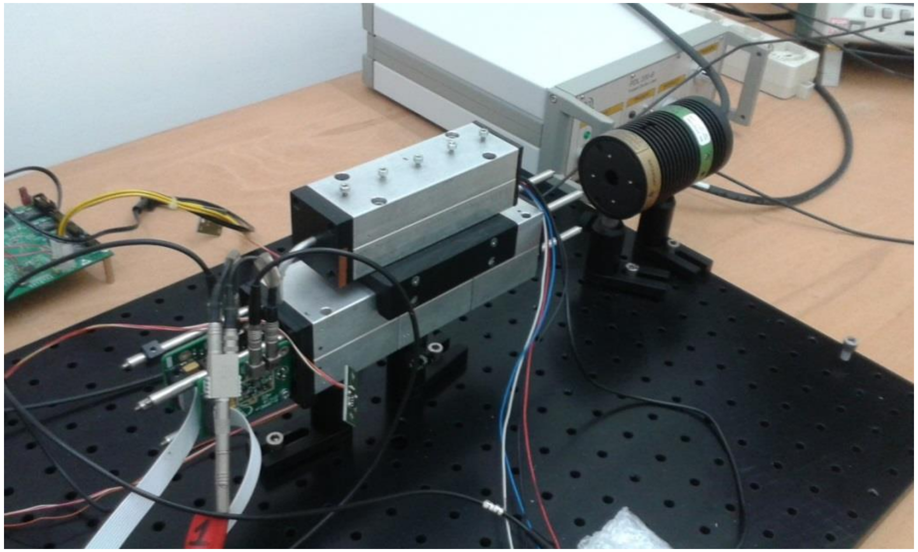
- PMT (H5783-04)
  - amplified by custom frontend electronics
  - receives light pulses transmitted from the mixing chamber to the photocathode by wavelength-shifting fibers
  - light pulses which are emitted by a weak (~ 5-10 Hz) Am source (deposited on an NaI crystal, enclosed in an aluminium cylinder with a quartz window) are situated close to the PMT photocathode
  - the signal from the Am source serves as an absolute reference to aid with the relatively poor stability (e.g. strong dependence on HV) of PMTs

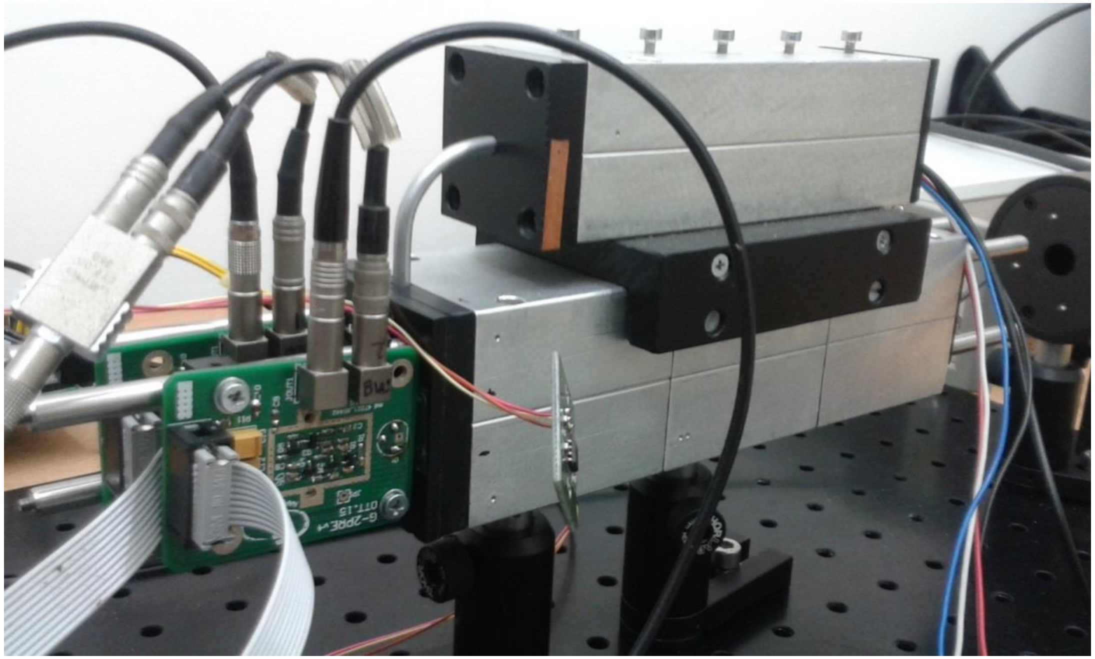

DRS4 (WFD)
SMB
LCB


Sepia II
SM
Trigger OUT

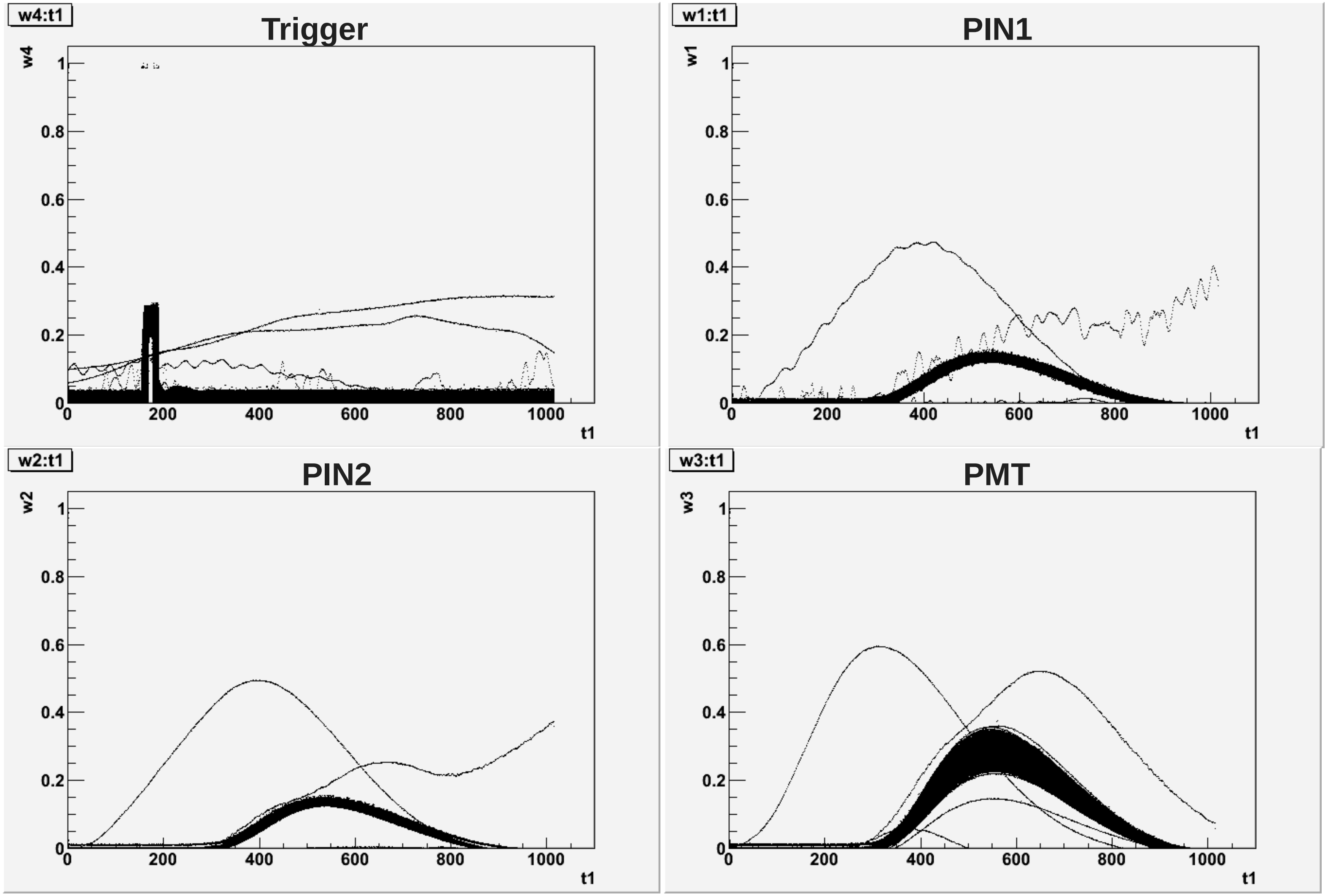

WFD OUT
PIN1 IN
PIN2 IN
PMT IN







Input pulse : 180 pJ Pulse rate: < 1 Hz,
Run time: 16 h WFD: DRS4



Chanel output (V) vs Time (ns)

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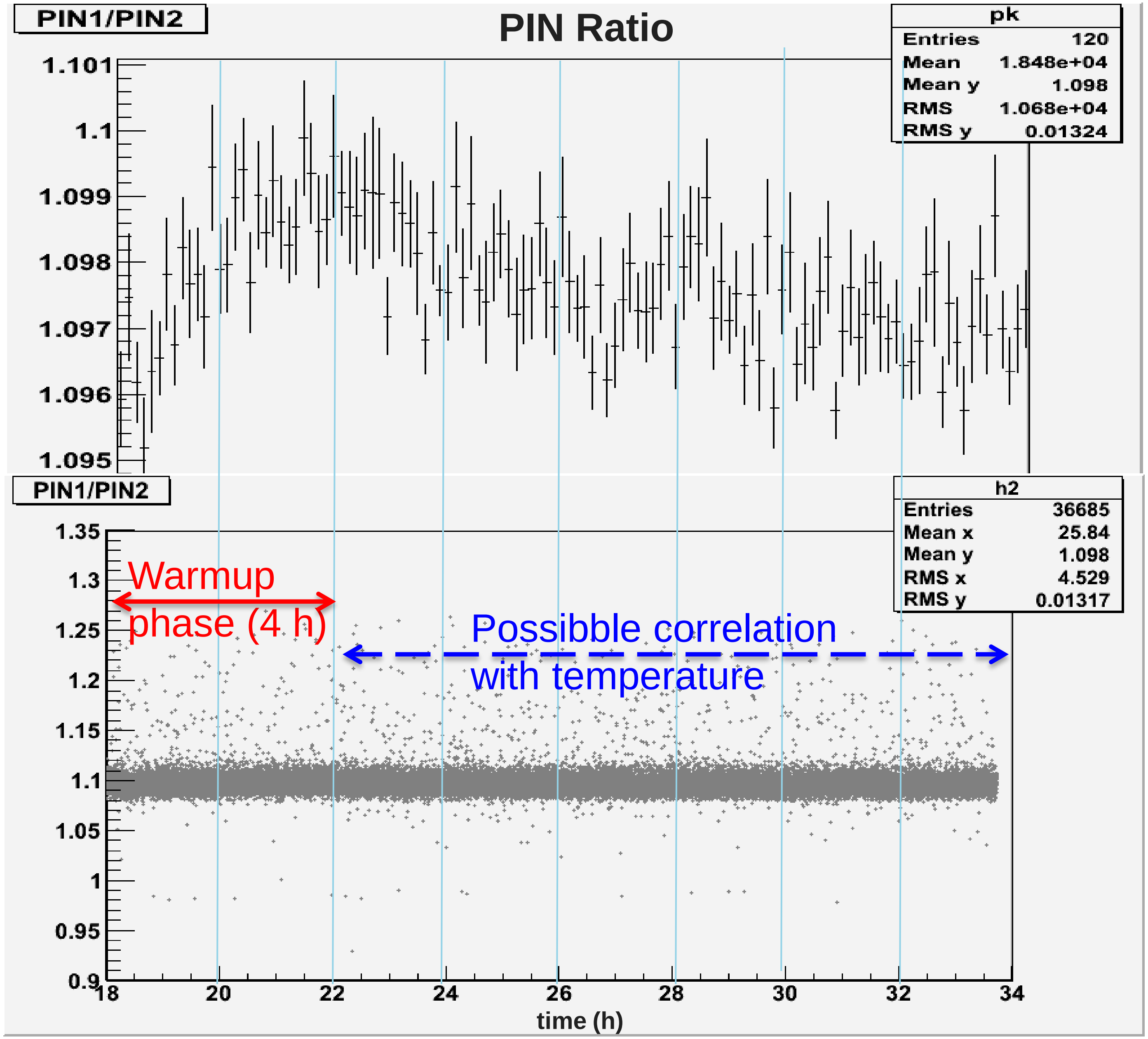
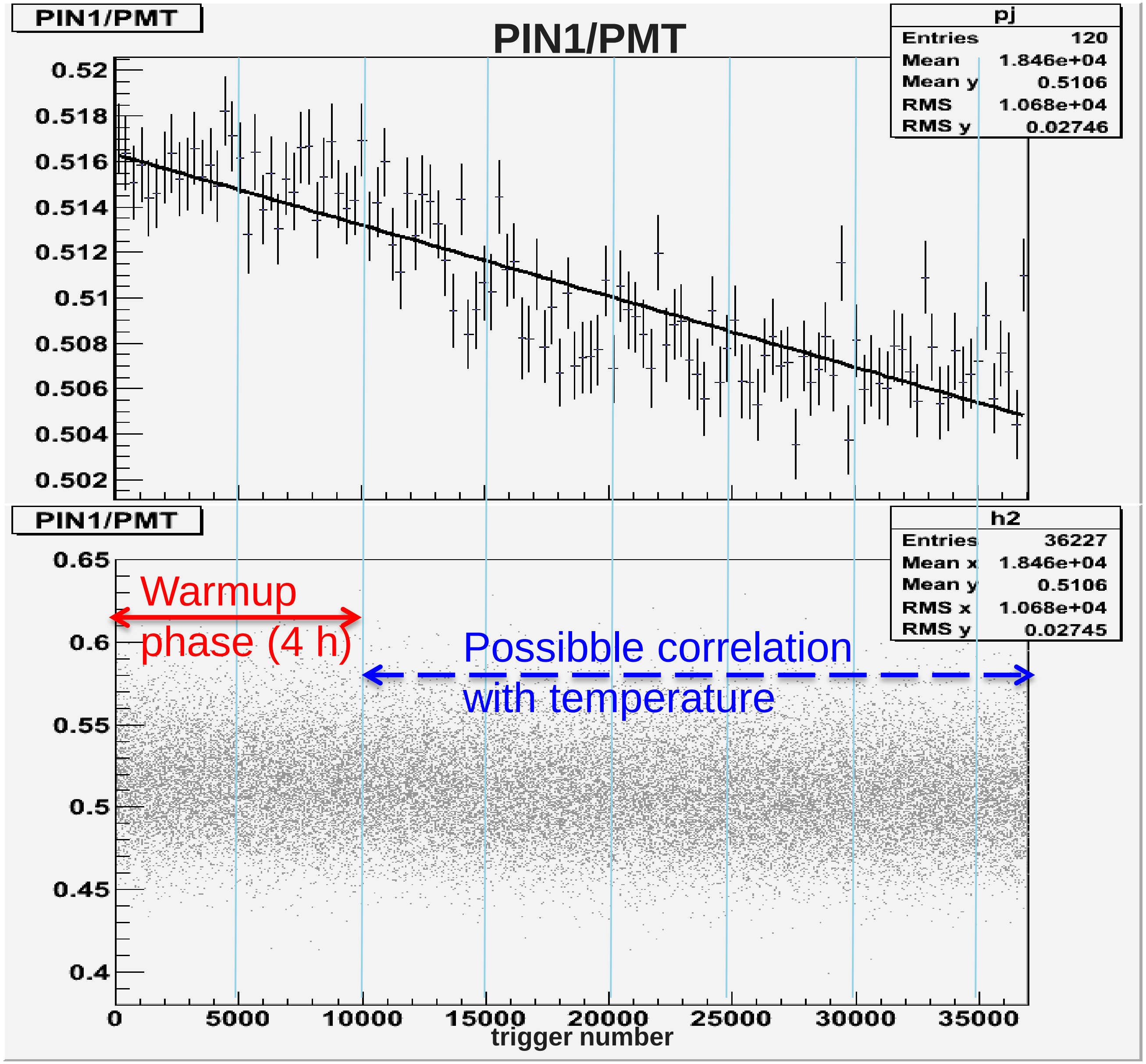
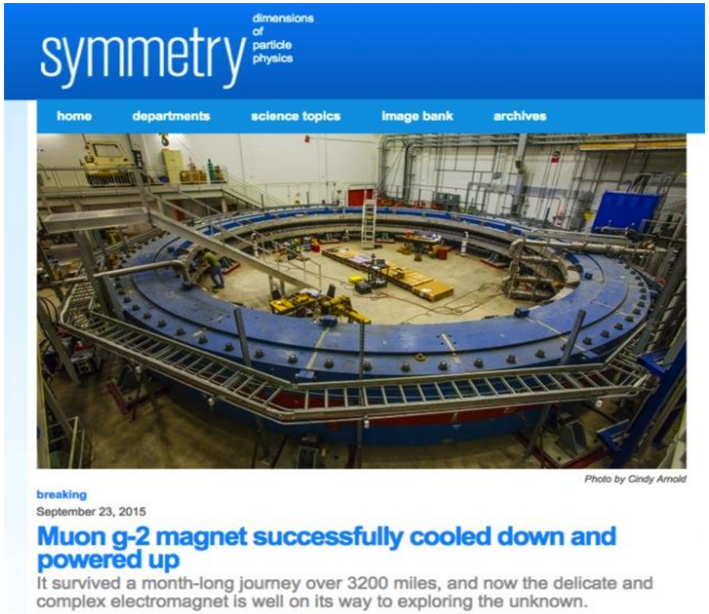

PIN1/PIN2
PIN Ratio
pk
Entries 120
Mean 1.848e+04
Mean y 1.098
RMS 1.068e+04
RMS y 0.01324
1.101
1.1
1.099
1.098
1.097
1.096
1.095
PIN1/PIN2
h2
Entries 36685
Mean x 25.84
Mean y 1.098
RMS x 4.529
RMS y 0.01317
1.35
1.3
1.25
1.2
1.15
1.1
1.05
1
0.95
0.9
18
20
22
24
26
28
30
32
34
time (h)
Warmup phase (4 h)
Possibble correlation with temperature


PIN1/PMT
PIN1/PMT
pj
Entries 120
Mean 1.846e+04
Mean y 0.5106
RMS 1.068e+04
RMS y 0.02746
0.52
0.518
0.516
0.514
0.512
0.51
0.508
0.506
0.504
0.502
PIN1/PMT
h2
Entries 36227
Mean x 1.846e+04
Mean y 0.5106
RMS x 1.068e+04
RMS y 0.02745
0.65
0.6
0.55
0.5
0.45
0.4
0 5000 10000 15000 20000 25000 30000 35000
trigger number
Warmup phase (4 h)
Possibble correlation with temperature

Closing remarks

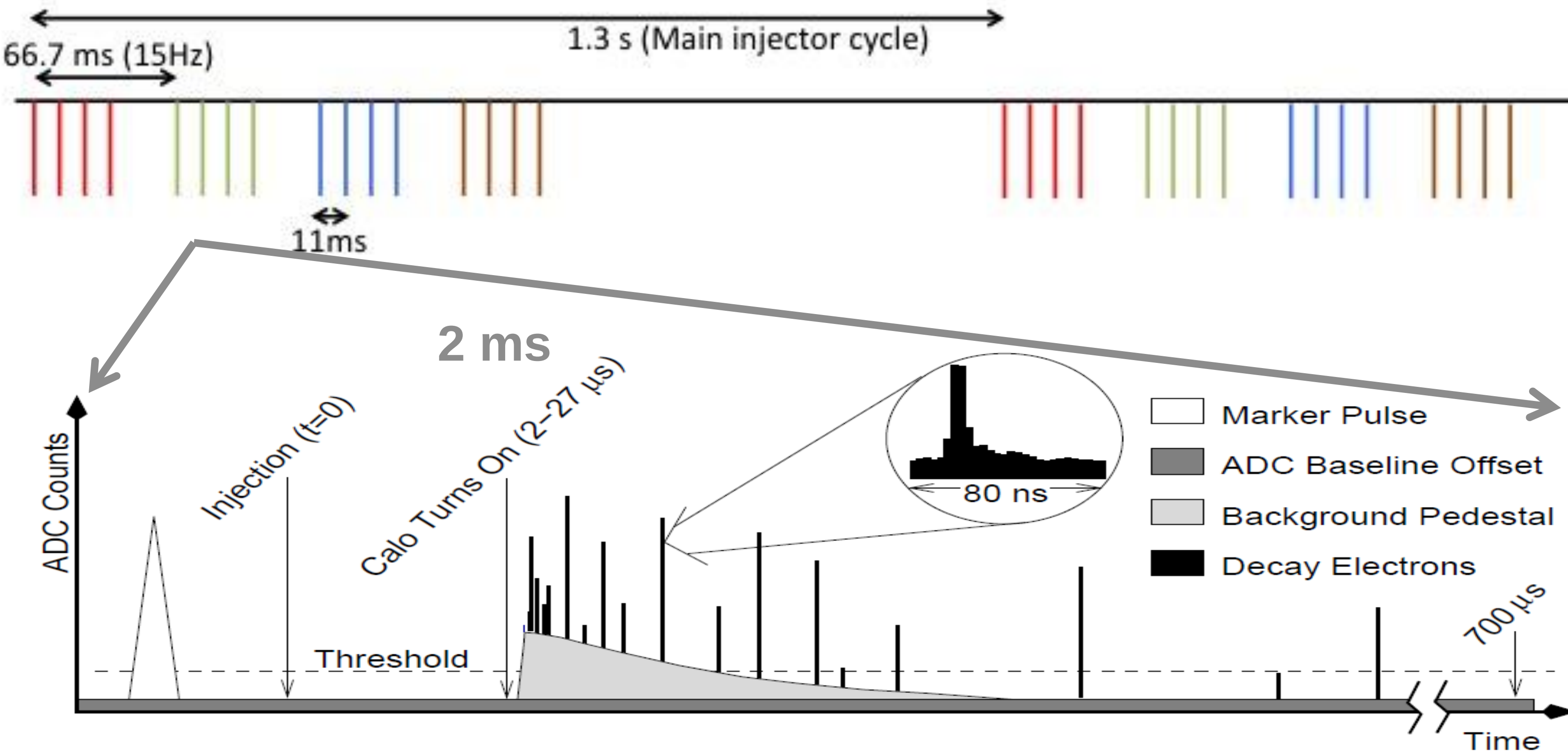
- Storage ring is cold and powered
  - Installation in 2nd half of 2016
  - Muons in 2017

- Laser calibration system will aid in obtaining 0.01 ppm statistical uncertainty
  - Monitoring equipment is ready for installation
  - Temperature and electronic baseline fluctuations must be well understood (frontend electronics)




Thank you!
50

Backup



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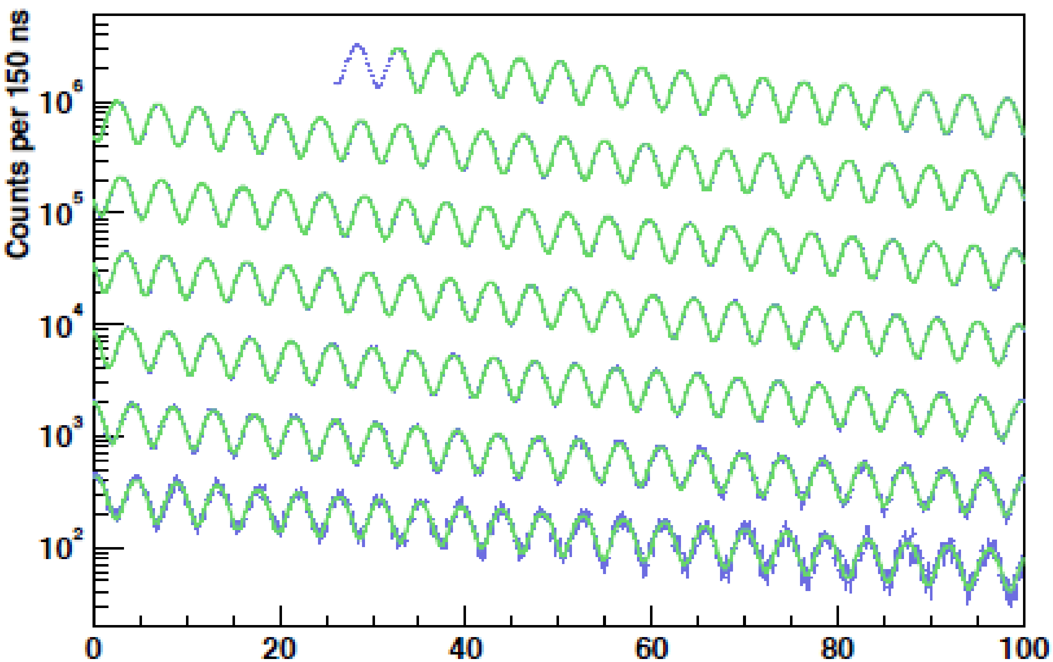
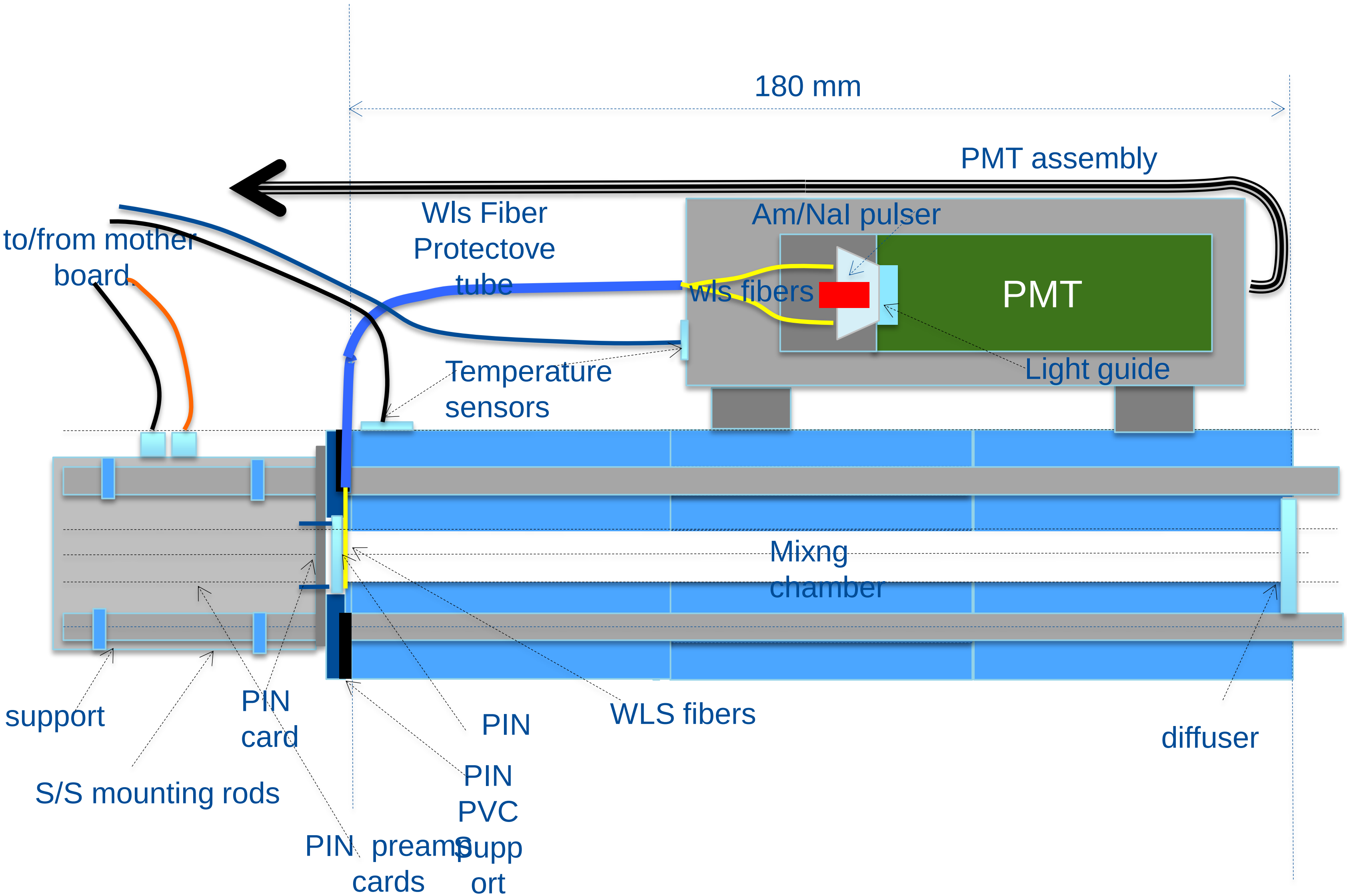
Experiment Background: Measuring aµ

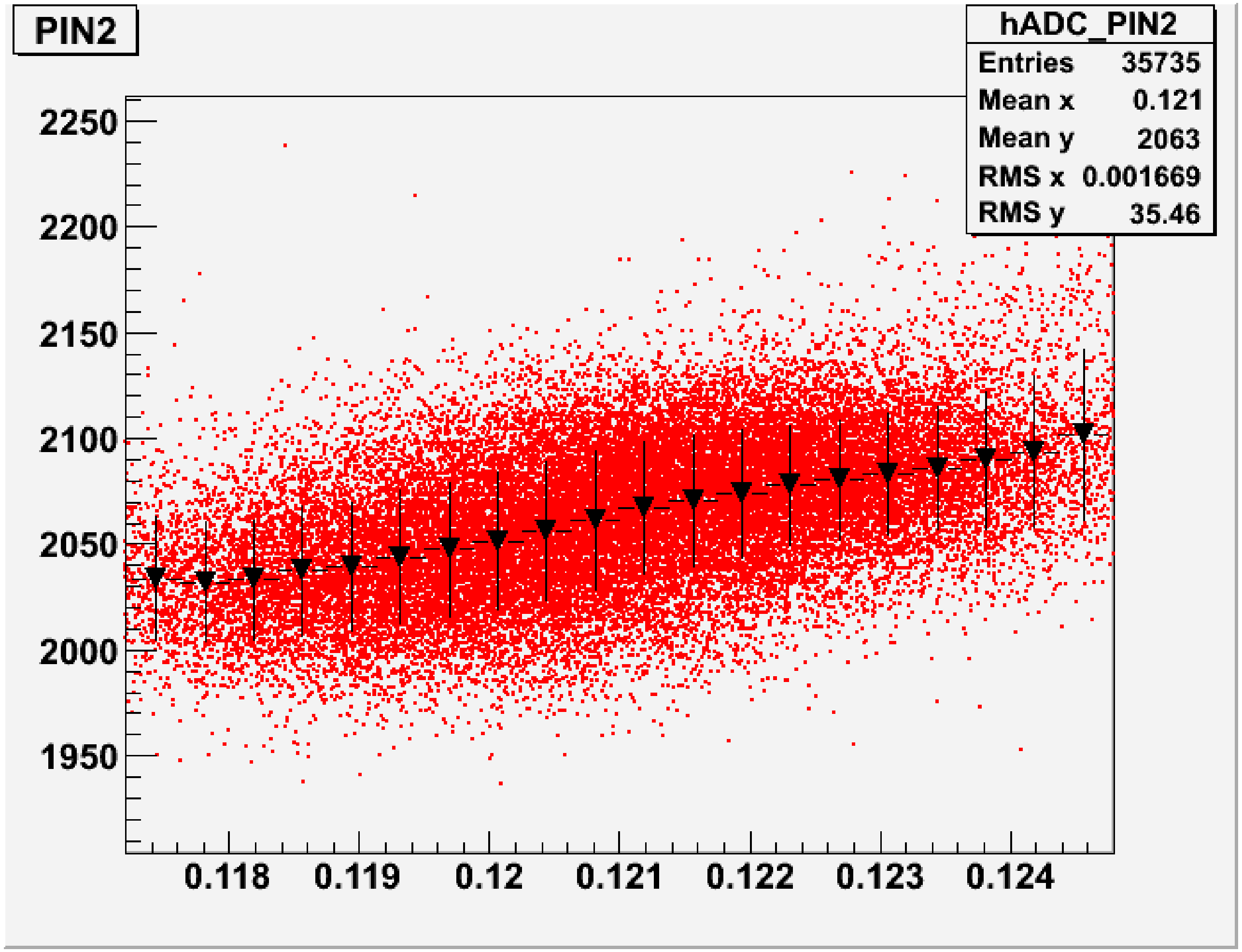
Decay electron data from E-821



BNL Data Report (2000)

- How it works
  - 3.1 GeV/c muons produced from pion decay channel are fed into 14m diameter, 1.45T magnet
  - Decaying muons emit electrons which curl towards ring interior and are collected by calorimeters

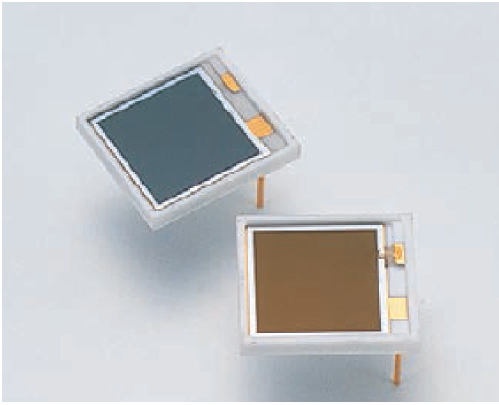

180 mm
PMT assembly
to/from mother board
Wls Fiber Protectove tube
Am/NaI pulser
wls fibers
PMT
Temperature sensors
Light guide
Mixng chamber
support
PIN card
PIN
WLS fibers
diffuser
S/S mounting rods
PIN PVC Support
PIN preamp cards



PIN2
hADC_PIN2
Entries 35735
Mean x 0.121
Mean y 2063
RMS x 0.001669
RMS y 35.46
2250
2200
2150
2100
2050
2000
1950
0.118
0.119
0.12
0.121
0.122
0.123
0.124

HAMAMATSU

PHOTON IS OUR BUSINESS



Si PIN photodiode

S3590-08/-09/-18/-19

Large active area Si PIN photodiode

Structure / Absolute maximum ratings

Type No.	Window material	Active area (mm)	Depletion layer thickness (mm)	Absolute maximum ratings: Reverse voltage VR max	Absolute maximum ratings: Power dissipation P (mW)	Absolute maximum ratings: Operating temperature Topr (°C)	Absolute maximum ratings: Storage temperature Tstg (°C)
S3590-08	Epoxy resin	10 × 10	0.3	100	100	-20 to +60	-20 to +80
S3590-09	Unsealed						
S3590-18	Epoxy resin						
S3590-19	Unsealed						

Note: Exceeding the absolute maximum ratings even momentarily may cause a drop in product quality. Always be sure to use the product within the absolute maximum ratings.

Electrical and optical characteristics (Typ. Ta=25 °C, unless otherwise noted)

Type No.	Spectral response range λ (nm)	Peak sensitivity wavelength λp (nm)	Photo sensitivity S: λ=λp (A/W)	Photo sensitivity S: LSO 420 nm (A/W)	Photo sensitivity S: BGO 480 nm (A/W)	Photo sensitivity S: CsI(TI) 540 nm (A/W)	Short circuit current Isc 100 *lx* (μA)	Dark current ID VR=70 V Typ. (nA)	Dark current ID VR=70 V Max. (nA)	Temp. coefficient of ID TCID VR=70 V (times/°C)	Cut-off Frequency fc VR=70 V (MHz)	Terminal capacitance Ct f=1MHz VR=70 V (pF)	NEP VR=70 V (W/Hz$^{1/2}$)
S3590-08	340 to 1100	960	0.66	0.20	0.30	0.36	100	2	6	1.12	40	40	3.8×10^{-14}
S3590-09				0.22	0.33	0.41	90						
S3590-18			0.65	0.28	0.34	0.38	100	4	10				7.6×10^{-14}
S3590-19			0.58	0.33	0.37	0.4	86						

PMT (H5783-04) specifications

According to manual at *http://html.alldatasheet.com/html-pdf/62598/HAMAMATSU/H5783-04/407/1/H5783-04.html*

Product Variations

Type No. \ Suffix	None	-01	-02	-03	-04	-06	-20	Output Type	Features
H5773	yes	yes	yes	yes	yes	yes	yes	On-board	Low power consumption
H5783	yes	yes	yes	yes	yes	yes	yes	Cable output	
H5773P	yes	no	no	no	no	no	no	On-board	For photon counting
H5783P	yes	no	no	no	no	no	no	Cable output	Low power consumption
H6779	yes	yes	yes	yes	yes	yes	yes	On-board	Low ripple noise
H6780	yes	yes	yes	yes	yes	yes	yes	Cable output	Fast settling time

Suffix	Spectral Response
None	300 nm to 650 nm
-01	300 nm to 850 nm
-02	300 nm to 880 nm
-03	185 nm to 650 nm
-04	185 nm to 850 nm
-06	185 nm to 650 nm
-20	300 nm to 900 nm

The suffix -06 type (synthetic silica window) has higher sensitivity than the -03 type below 300 nm in wavelength range.

Specifications

Parameter	H5773 / H5783 / H6779 / H6780 Series					Unit
Suffix	None	-03, -06	-01, -04	-02	-20	—
Input Voltage	+11.5 to +15.5					V
Max. Input Voltage	+18					V
Max. Input Current	H5773 / H5783 Series: 9 H6779 / H6780 Series: 30					mA
Max. Output Signal Current	100					μA
Max. Control Voltage	+1.0 (Input impedance 100 kΩ)					V
Recommended Control Voltage Adjustment Range	+0.25 to +0.9					V
Effective Area	ϕ8					mm

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